ASSESSMENT OF THE LOCAL BIAXIAL ACTIVE MECHANICAL PROPERTIES OF PIG ASCENDING AORTA

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INTRODUCTION

The complex hemodynamics of the left ventricle outflow tract (LVOT) combined with the complex geometry of the ascending aorta (AA) produce a non-uniform shear stress distribution on the AA wall [1]. Endothelial cells are known to be sensitive to shear stress and can lead to vascular remodeling. We hypothesize that a non-uniform morphological adaptation occurs in the AA tissue leading to the change of the local mechanical properties. It is known that AA's wall is composed of passive (elastin & collagen) and active elements (vascular smooth muscles cells, VSMCs). No data currently exists about local active mechanical properties assessment under biaxial testing. We therefore evaluated both the local passive and active mechanical properties of pig AA.

METHODS

All tissues were collected from sacrificed healthy pig. Two squared samples of 15.0 X 15.0 mm are carefully sectioned from each aortic ring: inner curvature (ic) and outer curvature (oc). The circumferential side of each sample was carefully identified for testing purposes. Mechanical testing was performed using a biaxial tensile tester, EnduraTEC Electro Force 3200 (Bose, Minnesota, USA). A equi-biaxial test was performed: 10 cycles of preconditioning cycles and three experimental runs to 30% strain at a strain rate of 0.1 mm/s. At the end of each passive mechanical testing, Phenylephrine at a concentration of 10^{-5}M was added to solution. Once maximum contraction of VSMCs was reached, biaxial testing was performed according to passive mechanical testing protocol for comparison. Incremental moduli of elasticity were obtained at a low (7.5%) and a high (25%) strain values from the stress-strain curves. Anisotropy was calculated by taking the difference between the circumferential stiffness and the axial stiffness divided by the average of both stiffness values (Equation 1). To quantify the contribution of VSMCs on stiffness, the stiffness index was calculated by taking the difference between stiffness obtained under passive and active testing divided by the average of both stiffness values (Equation 2).

$$AI = \frac{2(E_{circ} - E_{axial})}{E_{circ} + E_{axial}} \quad (1) \qquad SI = \frac{2(E_{active} - E_{passive})}{E_{active} + E_{passive}} \quad (2)$$

RESULTS AND DISCUSSION

Active testing showed that VSMCs have a non-negligible effect on aortic tissues mechanical properties. Tissue testing showed a positive stiffness index (SI) meaning an increase of stiffness under active testing in comparison to passive testing (Figure 1). Owing to the small number of aortic tissue samples tested, we could not find any significant differences between the inner and outer curvatures or at different strains. However, SI has a tendency to be the highest at low strain value and to vary locally. Previous studies have suggested that the effect of VSMC is strain dependent [2]. VSMCs may increase tissue stiffness at low strain but as tissue stretches, actin and myosin filaments do not overlap anymore and then active mechanical stiffness decrease toward passive mechanical stiffness value at high strain, toward a SI of zero. Moreover, we observed a tendency that the inner curvature had a larger SI than the outer curvature suggesting either a higher VSMCs content or more active VSMCs in this quadrant. Local quantification of VSMCs still needs to be performed. Figure 2 shows the effect of VSMCs on the anisotropic properties of tissues. Here again, because of the number of aortic tissue tested, we did not find any significant differences. However, we observed an increase of anisotropy for both quadrants with increasing strain and variations in anisotropy between quadrants at low and high strain. This increase is explained by the circumferential orientation of VSMCs. We did expect a larger variation between passive and active testing but the axial response had a larger response than expected. It has been suggest that extracellular matrix transmits VSMCs contraction not only in the circumferential direction but also in the axial direction [3].

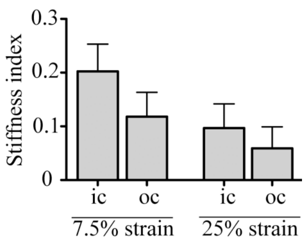

Figure 1. Local stiffness index.

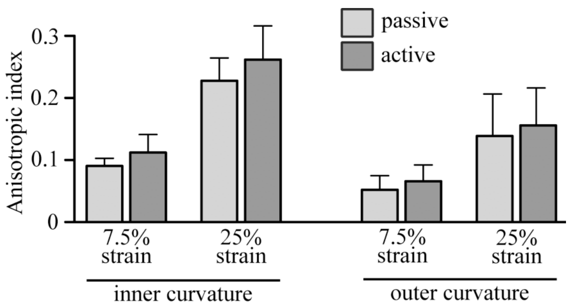

Figure 2. Local anisotropic index.

CONCLUSIONS

There is a significant increase in stiffness under active testing. VSMCs appear to have a greater effect on the stiffness at low strain value and at the inner curvature quadrant. More data needs to be obtained to verify if a significant increase in anisotropy occurs under active testing and if active testing effects the local variations of anisotropic properties.

REFERENCES

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